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FINAL REPORT
DESIGN, FABRICATION AND TESTING
OF
BLOCK IV DESIGN SOLAR CELL MODULES
PART II: RESIDENTIAL MODULE

APRIL 1982

(NASA-CR-169158) DESIGN, FABRICATION AND
TEST OF BLOCK 4 DESIGN SOLAR CELL MODULES.

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PART 2: RESIDENTIAL MODULE Final Report

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CHATSWORTH, CALIFORNIA 91311

PREPARED UNDER CONTRACT NO. 955402

FOR
JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA 91103



FINAL REPORT
DESIGN, FABRICATION AND TEST
OF
BLOCK IV DESIGN SOLAR CELL MODULES
PART II: RESIDENTIAL MODULE
APRIL 1982

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PREPARED UNDER CONTRACT NO. 955403
FOR
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The JPL Flat-Plate Solar Array Project is sponsored by the U.S. Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology by agreement between NASA and DOE, under NASA Contract.

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ARCO Solar, Inc. believes there are no Subject Inventions made under this contract.

ABSTRACT

This final design report concludes work performed on the design, fabrication and test of the Block IV Residential Load Module by ARCO Solar, Inc. This report outlines design changes from the proposed module design through three iterations to the discontinuance of testing agreed upon by both JPL and ARCO Solar, Inc.

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INTRODUCTION

Part II of this report contains the program plan, design data and engineering and manufacturing documentation produced during the development and testing of a Residential Load module by ARCO Solar, Inc. The module described in this report includes two major innovations developed by ARCO for use on the John Long Home Project and proposed for use in the Block IV Residential Program. These are the use of ethylene/vinyl acetate (EVA) encapsulant and a Tedlar® film plastic front cover in a batten and seam roofing design. The design responds to requirements outlined by the Jet Propulsion Laboratory Document No. 5101-83, "Block IV Solar Cell Module Design and Test Specifications for Residential Applications," November 1, 1978.

PROGRAM OUTLINE

The program followed by ARCO Solar, Inc. during the design and fabrication of the Residential Module deviated from that proposed as we gained experience with the new plastic front, steel substrate module design. The major steps in the program included the following tasks:

1. Module design, including layouts, details and assembly drawings.
2. Design reviews with JPL to approve the Engineering, Manufacturing and Quality Control Documents.
3. Submittal of seven modules for qualification testing.
4. Submittal of the Final Design Report.

DESCRIPTION OF DESIGN

The concept for the /S, Inc. Residential Module Design was based on a low-cost, batten and seam approach. This design was aimed at providing a module for use on rooftops of homes, apartment complexes and business offices. By eliminating the costly and heavy glass front typifying most photovoltaic module designs, the steel substrate could be a larger, 2-x4-foot size, well suited for the roofing installation business as it allows for the seams to be on 2 foot centers. Several iterations in the design occurred as we gained knowledge through the fabrication of modules for the John Long Project and the building of test samples for submittal to JPL.

Features common to all of the design iterations include the solar cell and circuitry design. Cells are 4.05 inches in diameter, single crystal grown by Czochralski technique. The ingots are sliced into wafers, texture etched and diffused for a shallow junction. Discrete pad ohmic contacts are printed using a thick film paste of silver on the front and a combination of silver and aluminum on the back surface. This printing technique is amenable to high volume and is presently used in our manufacturing plant.

Contact to the cell comes from the soldering of coated copper buss ribbon across the faces of the cell. Dual redundant ribbons on both front and back, soldered in many places, reduce the risk of power loss due to cell breakage. The contacts made to the discrete ohmic pads also allow for strain relief during thermal excursions.

The circuitry of three parallel strings allows for more fault protection than a single string module, and reducing the number of cells in series to 20 reduces the amount of hot spot heating possible. The provision of a bypass diode external to the circuit also reduces the hot spot problem.

Other features common to all iterations include the use of a plastic coated steel substrate with thin plastic film cover. This allows for lighter weight and less cost per area compared to glass front designs. Ethylene/vinyl acetate (EVA) pottant was used on all iterations for its superior hot spot endurance and lower moisture permeability.

Dual redundant terminations are a common feature in all of the rooftop designs as it provides for easy interconnection of modules under the battens. Grounding of modules also takes place here with the use of sheet metal screws through tabs on the substrate pan. Overlapping of modules combined with batten-covered edges gives water-repellant electrical connections and high packing density on the roof.

As outlined in the original proposal, the first design iteration included a Korad® acrylic film-coated steel substrate, EVA encapsulant and clear Korad® film cover. This design was used on the John Long Project and included a bent copper clip termination. Buss bars protruded from the laminate and bent over the flanges of the module pan. The clips were forced over these buss bars to make contact.

Several problems were encountered with this design, the major being electrical isolation of conductive components. The Korad® coating on the substrate pan was easily scratched, providing a shorting path to ground. Dielectric standoff was adequate as long as no scratches occurred. The spring clip and buss bar folded around the pan also posed an electrical standoff problem. Nomex® dielectric paper and polyester tape used in the terminal area provided the necessary isolation here. A secondary problem with this design was the moisture pick-up by the Korad® film. Evidence of this problem was seen during internal ARCO Solar qualification testing.

Because of the problems associated with Korad®, a new film was used in the second design. The second design incorporated Tedlar®-coated steel substrate pans and a clear film of 0.002-inch-thick Tedlar® as a cover sheet. Terminations included dual positive and negative pigtails. The substrate pan was used as a strain relief in this design. The diode was also changed to accept a higher current level. Seven modules of this version were submitted to JPL for testing. Internal qualification testing at AS, Inc. during the time of submittal showed some problems with this design also. The 2-mil Tedlar® cover film shrank excessively at high temperatures causing the film to peel away from the edges and resulting in delamination. The modules were recalled from JPL for a new submittal.

The third version of the design substituted 4-mil Tedlar® as a cover film to help the shrinkage problem. Seven new modules were submitted for test. Nine modules of this design were also submitted to AS, Inc. internal testing. After exposure to the Block IV specified thermal cycling, delamination occurred in the terminal area on these nine. This is consistent with the findings of JPL testing. The delamination was caused by stressing of the Tedlar® when terminations were prepared and the Tedlar® appeared to pull back a certain amount then stop. The delamination did not appear to progress further with more exposure. The failure of these modules to meet the visual criteria outlined in the Block IV specification prohibited continuing of tests. An agreement by ARCO Solar, Inc. and JPL was reached to end the program.

DESIGN DATA

The key elements of the final design described above are outlined in Table 1. The cells, circuit and module are included.

The power output of the module at 28°C and 1000 W/m² is a nominal 62 watts. A typical I-V curve is shown in Figure 1 at these conditions.

Direct roof mounting of this module results in a high Nominal Operating Cell Temperature of 65°C (at 20°C ambient, 1000 W/m², 1 m/s wind). The module de-rating coefficients are 3.66 mA/°C/module and 49 mV/°C/module. Data at 28°C, 1000 W/m² and at NOCT, 1000 W/m² are given in Table II for both cell and module. The respective efficiencies are also included.

ENGINEERING AND MANUFACTURING DOCUMENTATION

Layouts, details and assembly drawings done for the Residential Block IV Module Design are attached as an appendix. The module drawings include the latest revision only. These drawings detail the module submitted for final testing.

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TABLE I

KEY ELEMENTS OF RESIDENTIAL MODULE DESIGN

CELLS

- 4.05 inch (103 mm) Czochralski single crystal silicon wafers, 12 mils thick
- Texture etched surface
- Discrete pad ohmic contacts, two sets
- Thick film printed silver front collection grid and contacts
- Thick film printed aluminum back collector
- Shallow diffusion

CIRCUIT

- Redundant buss bar interconnects
- Discrete pad ohmic contact system for stress relief
- 60 cells connected in three series strings of 20 each protected by external diode

MODULE

- 2-x4-foot nominal size
- Tedlar® coated steel substrate
- Clear Tedlar® cover film
- Two sets of pigtails, one each on either side of module

FIGURE 1

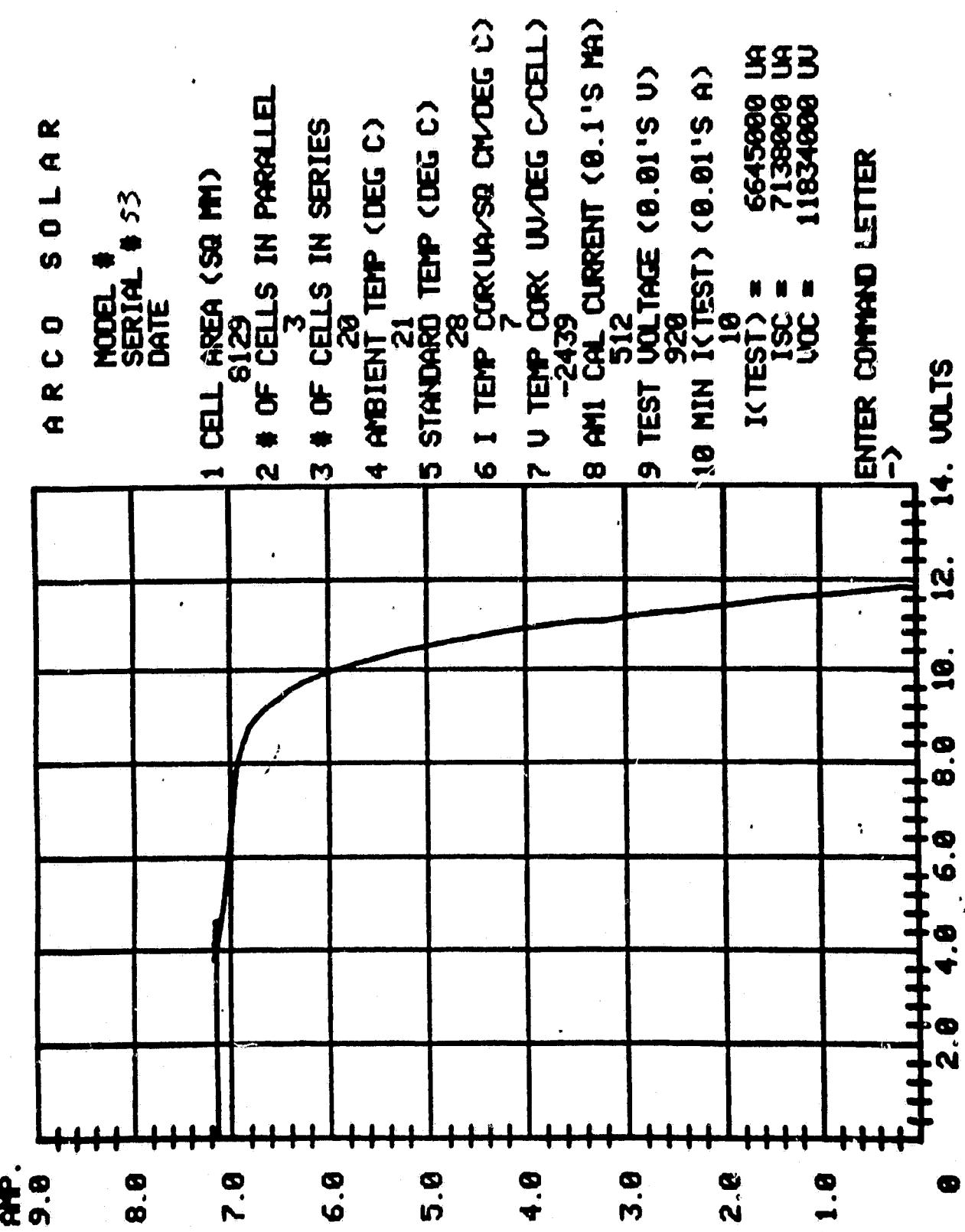


TABLE II

CELL/MODULE CHARACTERISTICSRESIDENTIAL BLOCK IV DESIGNAM 1.5 1000 W/m²

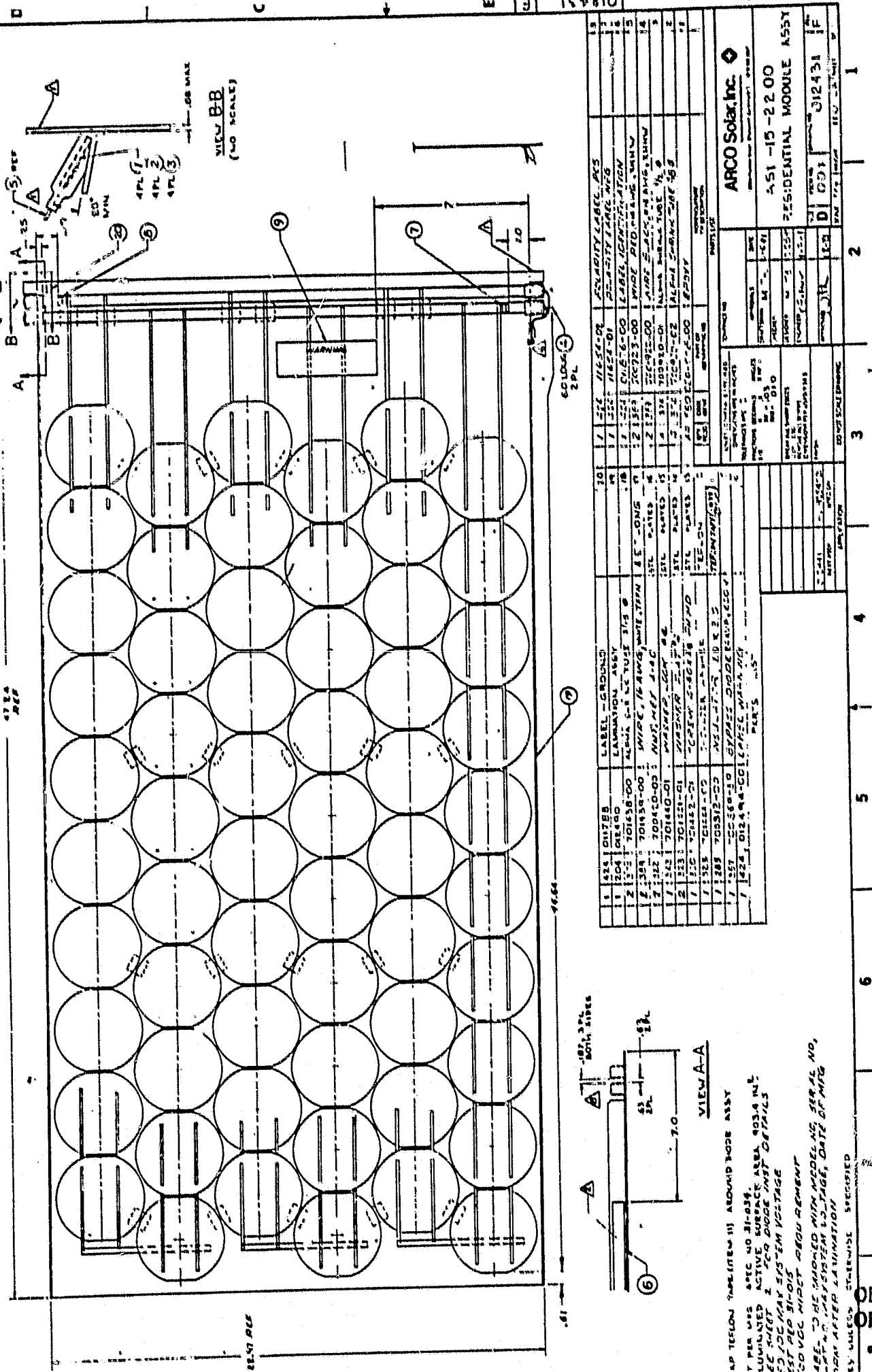
	<u>CELL</u>		<u>MODULE</u>	
	<u>28°C</u>	<u>65°C</u>	<u>28°C</u>	<u>65°C</u>
V _{oc} , Volts	0.595	0.505	11.9	10.1
I _{sc} , Amps	2.30	2.32	7.04	7.10
V _L , Volts	0.480	0.390	9.60	7.80
I _L , Amps	2.15	2.17	6.58	6.64
P _L , Watts	1.03	0.85	63.2	51.8
η _{aa} *	12.6%	10.4%	13.0%	10.6%
η _{mod} *			9.8%	8.0%

Cell area: 81.3 cm²Module area: 6437.0 cm²

Three parallel strings of 20 cells each

*η_{aa} = efficiency based on cell area η_{mod} = efficiency based on module area

APPENDIX



ପାତାର ପାତାର ପାତାର

VEHICLE TESTED ~~VEHICLE TESTED~~ 111 AROUND 10000 MILES
CUT PER MILE 0.02 NO 31-034
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2 500 DIOCE INST. OPTICS
100% EFFECT

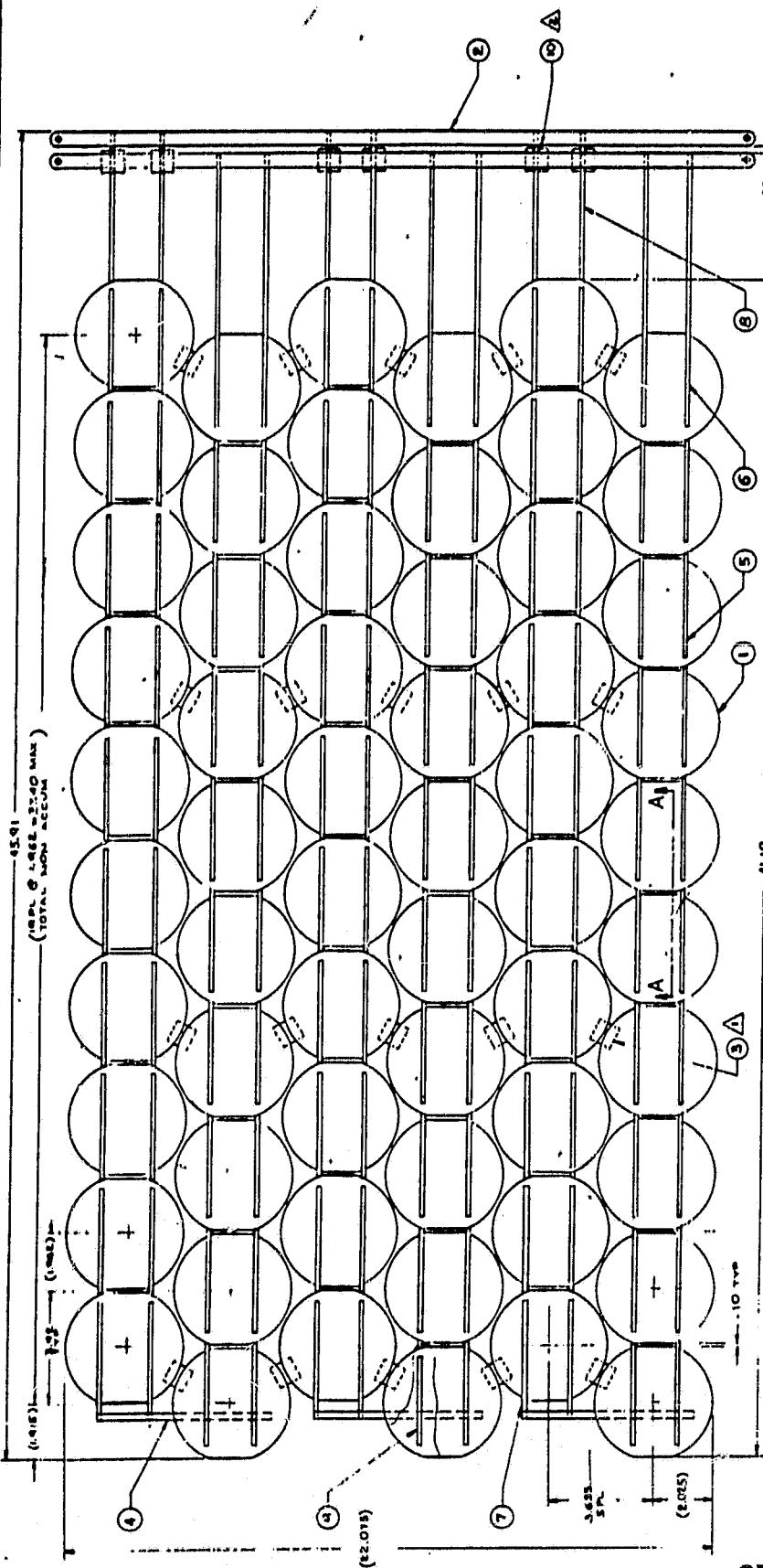
1500 INCHES PER HOUR SYSTEM VS/TAGE
5000 INCHES PER HOUR SYSTEM VS/TAGE
TEST PRO 51-015
5000 INCHES PER HOUR REQUIREMENT

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SEE SHEET 1				
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ARCO Solar, Inc.

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RE SOLDER FILE, SPEC 81-101
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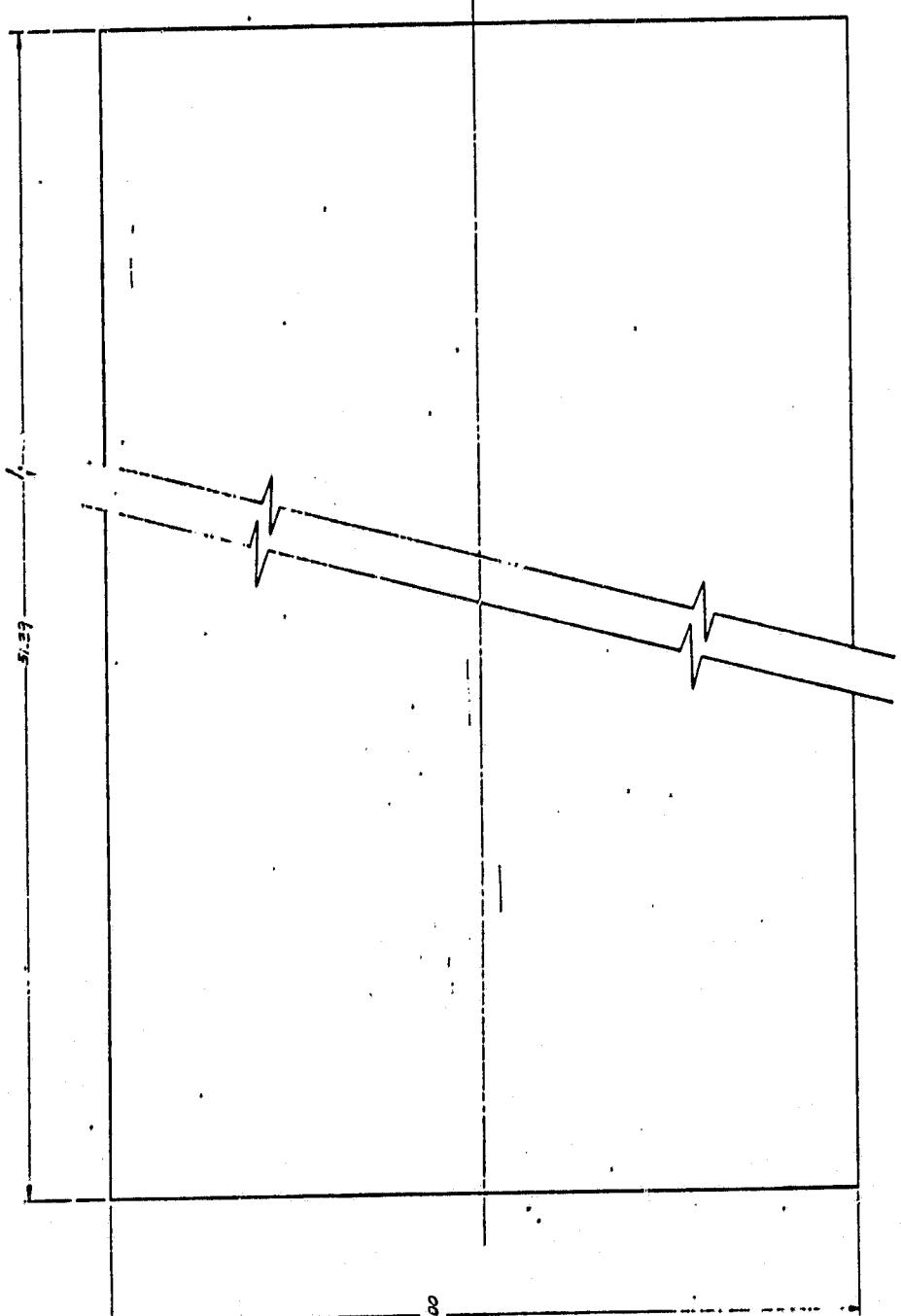
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C12433

1. COLOR: TECLEAR FILM CLEAR 1.004 TIRK

12. COLOR: CLEAR 1.004 SPECIFIED

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4	4	4	4
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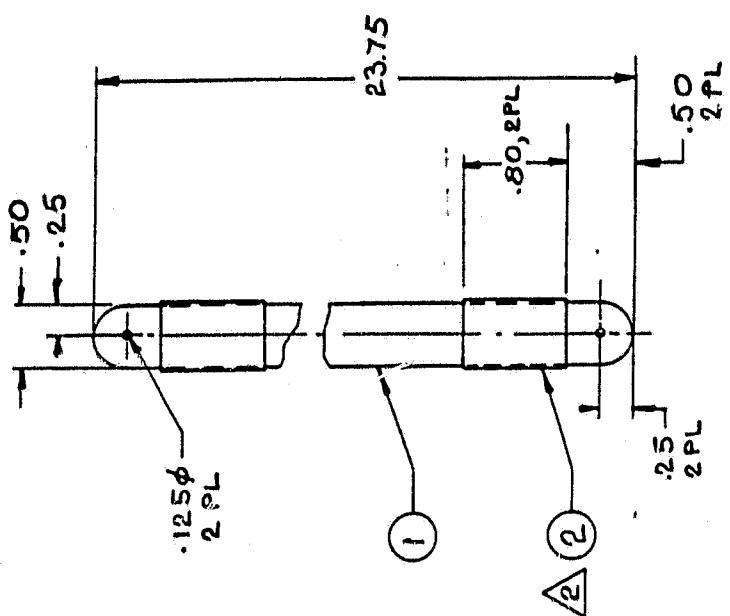
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Ref	Ext	Serial No.	Manufacturing Date	Serial No.	Manufacturing Date	Ref	Ext	Serial No.	Manufacturing Date	Serial No.	Manufacturing Date
ARCO Solar, Inc. ◊											
EVA EMISSIVE ANT. STREET											
RESIDENTIAL MODULE											
D 1243C											

651-110

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REVISIONS				APPROVED
ZONE	LTR	DESCRIPTION	DATE	
	-	RELEASED PER E&O 213	1-30-81	1/30/81
	A	REVISED PER E&O 246	2-26-81	2/26/81
	B	REVISED PER DRN 417	7-14-81	7/14/81



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QTY	CODE	PART NO	DESCRIPTION	ADHESIVE COATED TEDLAR RIBBON	(5.0 x 1.0)	2
ITEM				COPPER, .010THK	1	
2	256	700818-00				

ARCO Solar, Inc. <small>Subsidiary of Standard Oil Company 10000 Wilshire Boulevard Los Angeles, California 90021 (213) 529-0567</small>				CIRCUIT BUS RIBBON	
10000	APPROVALS	1-24-82	ITEM NO.	012489	REV.
10000	CRAFTSMAN	WTS	PRINTING NO.		
10000	INITIALS		SCALE	1/1	SWING
NOTE: UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE .005 INCHES FRACIONS DECIMALS AND INCHES USE .005 INCH TOLERANCE EX: 1-1/2" = .005" = .005" = .005"		DESIGNER ENGINEER DATE		SCALE ITEM NO. PRINTING NO.	
SHARP, ALL SHARP EDGES 1/8" OR 1/16" ON FOR WIRE, ALL BURRS DEBRIEFED PER DRAWING FINISH		1/12/82 1/12/82 1/12/82		1/1 WEIGHT SWING	
TESTED APPROVED APPLIED					

2. APPLY CLEAR TEFLON (ITEM 2)
WITH ADHESIVE SIDE TOWARD
BUS RIBBON AS SHOWN
1. COPPER RIBBON WITH SOLDER FINISH
SPEC 20-001

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2419 2419 2420 2421 2422 2423 2424 2425 2426 2427 2428 2429 2429 2430 2431 2432 2433 2434 2435 2436 2437 2438 2439 2439 2440 2441 2442 2443 2444 2445 2446 2447 2448 2449 2449 2450 2451 2452 2453 2454 2455 2456 2457 2458 2459 2459 2460 2461 2462 2463 2464 2465 2466 2467 2468 2469 2469 2470 2471 2472 2473 2474 2475 2476 2477 2478 2479 2479 2480 2

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NAME	ADDRESS	TELEGRAM	TELEPHONE	TELEGRAM	TELEPHONE
W. H. BROWN	1000 BROADWAY	W. H. BROWN	212-555-1234	W. H. BROWN	212-555-1234
W. H. BROWN	1000 BROADWAY	W. H. BROWN	212-555-1234	W. H. BROWN	212-555-1234
W. H. BROWN	1000 BROADWAY	W. H. BROWN	212-555-1234	W. H. BROWN	212-555-1234
W. H. BROWN	1000 BROADWAY	W. H. BROWN	212-555-1234	W. H. BROWN	212-555-1234

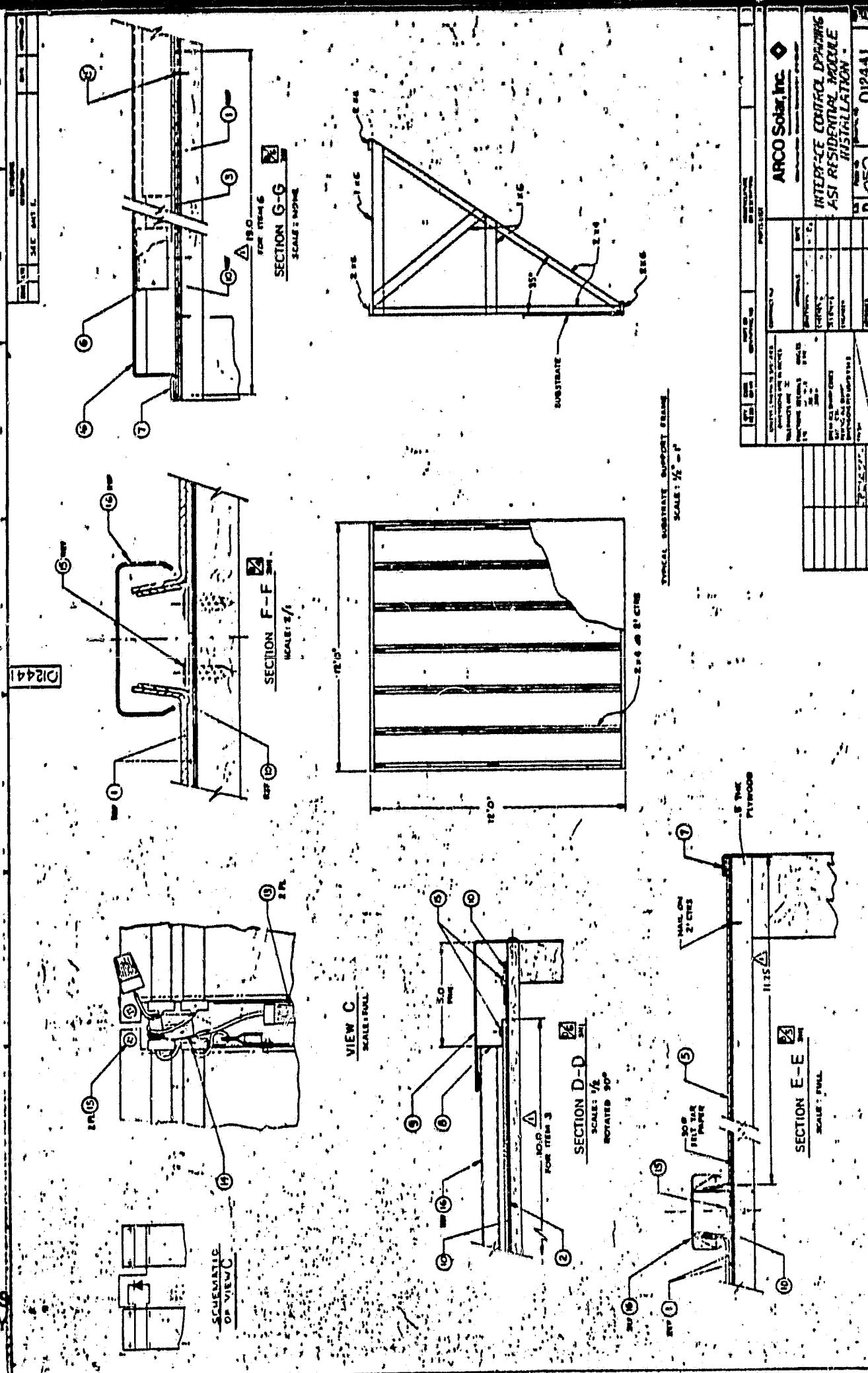
This technical drawing shows a structural frame with various components labeled and dimensioned. The frame consists of a central vertical column and horizontal beams. Callouts with circled numbers (1 through 9) point to specific parts: 1 points to the bottom horizontal beam; 2 points to the top horizontal beam; 3 points to the top horizontal beam near the center; 4 points to the bottom horizontal beam near the center; 5 points to the top horizontal beam near the right end; 6 points to the bottom horizontal beam near the right end; 7 points to the top horizontal beam near the left end; 8 points to the bottom horizontal beam near the left end; and 9 points to the vertical column. A callout labeled 'D' points to a vertical column on the left. A callout labeled 'E' points to a vertical column on the right. A callout labeled 'SEE VIEW A' points to a section of the top horizontal beam. Dimension lines indicate widths of 20.00, 20.00, and 20.00, and heights of 1.55, 1.55, and 1.55. A dimension of 2.25 is also shown.

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FAVERAGE - TBD
MAXIMUM OPERATING VOLTAGE - 12 V
CURRENS INSTILLED WITH IMPACT DRIVER -
SHADOW CONCRETE-TECH CO.
CAN PL. STEEL, SOURCE: DIAMOND TOOL SUPPLY
FREIGHT CHARGES TO FIT STARTER (ITEM 7) OR CLOUTER (ITEM 8).
NOTICE: WORKS CHEAPSE, SPECIFIED

FIG. VIEW A angle = 45°

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SOURCE: ARCHITECTURAL AND PRODUCTS
SAN DIEGO, CALIF.

3. LENGTH OF BALLOON: 12'-0" ±12"
CLOSING AT ONE END -01
OPEN AT BOTH ENDS -02
FINISH:
A. BOLD OUTSIDE OF BATTEN WITH .0015
STYLAR FILM COLOR CHARCOAL AND STYLIC

B. INSIDE TO HAVE A CLEAR EPOXY WA
.0004 THK. MAX

△ MATEL : 2.4 GAGE ZINC GALVAN
STEEL SHEET PER ASTM-A-44C, GRADE

NOTES: UNLESS OTHERWISE SPECIFIED

169110

REVISIONS		DESCRIPTION	DATE	REVISION NUMBER
REV	REV			
B		SECTION WITH CHANGES PER E.O. 113	1-16-57	REV B
C		REVISED PER E.O. 107	1-16-57	REV C
D		REVISED PER E.O. 213	1-10-57	REV D

-02
(open end)

Technical drawing of a component labeled 'C'. The drawing shows a rectangular base with a central circular hole. The overall width is 12.0, and the height is 12.0. A vertical slot on the left is 1.0 wide and 6.0 high. A vertical slot on the right is 1.25 wide and 1.50 high. The central circular hole has a diameter of 1.42.

VIENNA
—O!

012018	HAWAII		
012441	JPL		
012059	JICNG I		
012050	JICNG II		
012145	WET ASY		
	WSD001		APPLICATION

cm

ED DOCUMENT

169,1101

2

ARCO Solar, Inc. ♦
BATTEN
SI RESIDENTIAL MOD
011691

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REVISIONS

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action.

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4 DOCUMENT

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document contact

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FINISH: A BOND TOP OF PAJ WITH ADISTIK FILM COLOR CHARCOAL NO.150BL30CC.

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013.437

CONFIDENTIAL
For later rev.
docum. in class.

(22.97)

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22.70		22.70		22.70	
25R 2 PL		136 2 PL		10.00	

(22.97)

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REVISIONS

REV	REV	REV	REV
100	101	102	103
E-12 FOR PROD PIRE		E-13 FOR PROD PIRE	
A-REVISED PER EO 213		A-REVISED PER EO 213	

(22.97)

This technical drawing shows a rectangular part with several dimensions and features:

- Top edge: 25 R 2 PL
- Left edge: 22.70
- Bottom edge: 1.36 2 PL
- Bottom right corner: 0.00
- Left side features: 80° 2 PL, 38° 2 PL, and a 22.70 dimension.
- Right side features: 22.70 (repeated).

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THE ACTUAL VALUE OF THE SIDE FLANGES TO BE DETERMINED BY THE WIDTH OF THE RAVI STOCK (64.00 ± 25) AND THE PAN HELD TO 22.70 ± 0.3 . BOTH FLANGES TO BE EQUAL WITHIN ± 0.3 .

卷之三

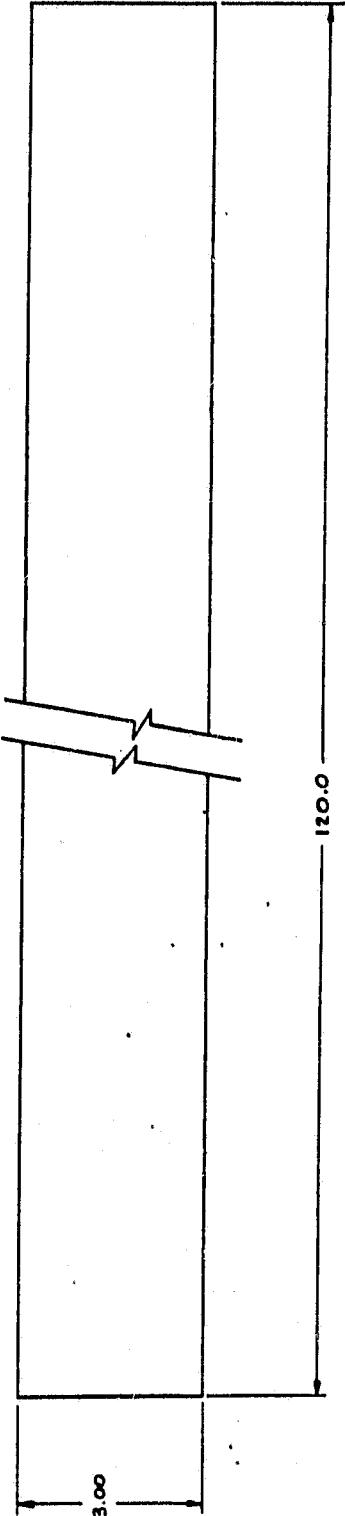
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REVISIONS	
DATE	11/18
RELEASE	PER DEV 272
APPROVED	3-16-81 ES/BS

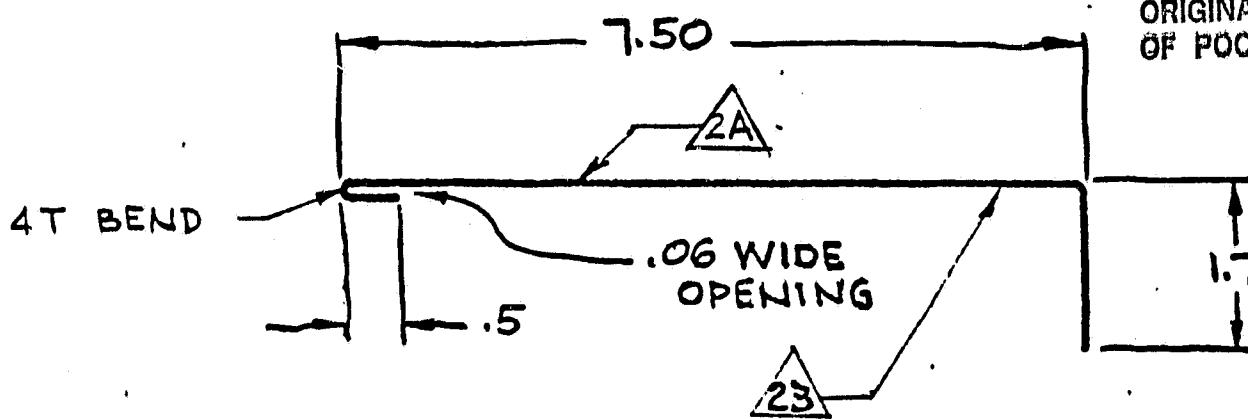
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REF ID	ITEM NO.	PART NO.	DESCRIPTION	INFORMATION OR DESCRIPTION
ARCO Solar, Inc.				
Dimension Line: 120.0				
1	270	120-1	WIRE RACEWAY PLATE, 120.0	1
2	270	120-2	RESIDENTIAL MODULE	1
3	270	120-3	120.0	1
4	270	120-4	120.0	1
5	270	120-5	120.0	1
6	270	120-6	120.0	1
7	270	120-7	120.0	1
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APPLICATION		REVISIONS			
ITEM ASST	USED ON	ITR	DESCRIPTION	DATE	APPROVED
			RLSE. FOR PROD PER EO 187	1-8-81	2WJHS
	A	REVISED	PER EO 213	1-31-81	EGD



UNCONTROLLED DOCUMENT

For latest revision, check with document control.

3. LENGTH: 12' 0"
2. FINISH: A. .0015 THICK TEDLAR FILM, COLOR LEAD CHARCOAL #15QBL30CC ON SIDE SHOWN
B. OPPOSITE SIDE TO HAVE A CLEAR EPOXY WASH .0004 THICK MAX.
1. MATERIAL: 24 GAGE STEEL SHEET PER ASTM-A-446-76 GRADE "A" G-90 ZINC GALVANIZED

NOTES: UNLESS OTHERWISE SPECIFIED

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOL RANGES ARE ±
FRACTIONAL NUMBERS ANGLED
1/8 X 1/16 X 1/32 X 1/64
1/8 .035

BOLTS ALL SHARP EDGES
REMOVE ALL BURRS
DIMENSIONS PER DRAWING 145

ITEM NO. 1
EFFECTIVE DATE 1-1-81
EXPIRE DATE 1-31-81

CONTRACT NO.	
APPROVALS	DATE
DRAFTSMAN	M. JS.
CHECkER	12-30-80
DESIGNER	
ENGR/EE	Engineer
	1-8-81

ARCO Solar, Inc.

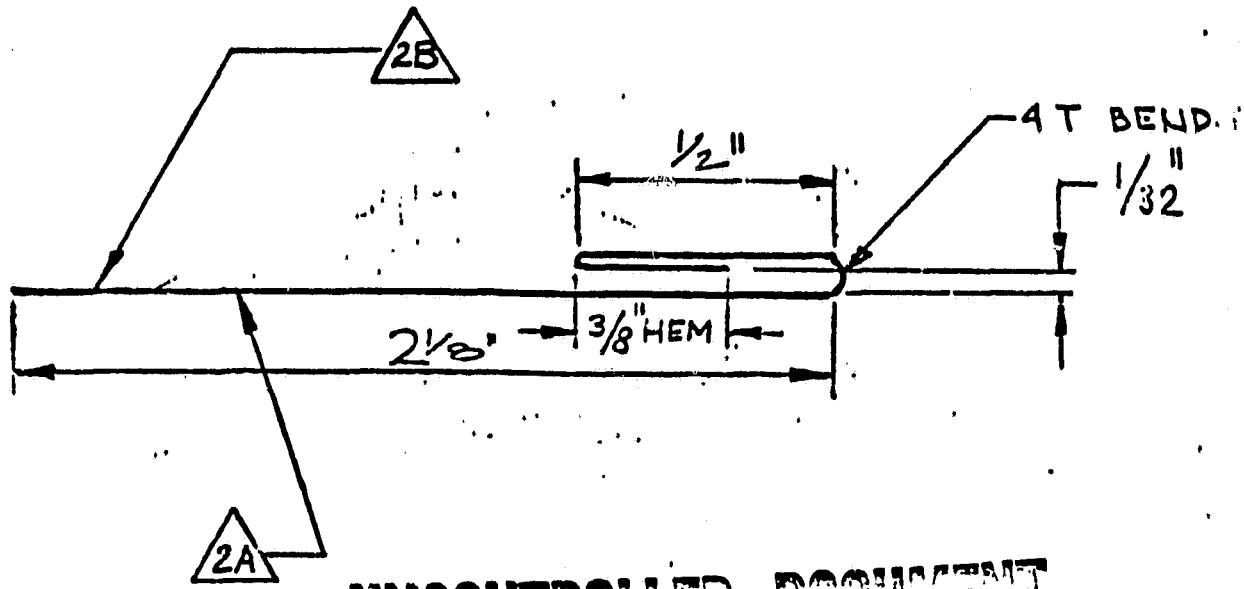


RIDGE COVER

A	270	DRAWING NO.	012440	REV. A
1/2	WEIGHT	1	0	1

APPLICATION		REVISIONS			
NEXT ASSY	USED CH	ITR	DESCRIPTION	DATE	APPROVED
012441	JPL		REL FOR PROD PER EO 192	1-8-81	Wata
		A	REVISED PER EO 213	1-31-81	Wata

ORIGINAL PAGE IS
OF POOR QUALITY



UNCONTROLLED DOCUMENT

For latest revision, check with
document control

3. LENGTH: 12' 0"

△ FINISH: A. .0015 THICK : TEDLAR FILM, COLOR CHARCOAL No.150BL300 CON SIDE SHOWN.
B. OPPOSITE SIDE TO HAVE A CLEAR EPOXY WASH .0004 THICK MAX.

1. MATERIAL: 24 GAGE STEEL SHEET PER ASTM-A-446
GRADE A, G-90 ZINC GALVANIZED.

NOTES: UNLESS OTHERWISE SPECIFIED

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ARE: \pm
FRACTIONS DECIMALS ANGLES
 $1/8$ $1/16$ $1/32$ $1/64$ $1/128$

BREAK ALL SHARP EDGES
0.000
REMOVE ALL BURRS
DIMENSION PER USASI Y 14.8

FINISH
△
DO NOT SCALE DRAWING

CONTRACT NO.

APPROVALS	DATE
DRAFTSMAN	K.S.
CHECHER	
DESIGNER	
ENCLOSURE	1-8-81

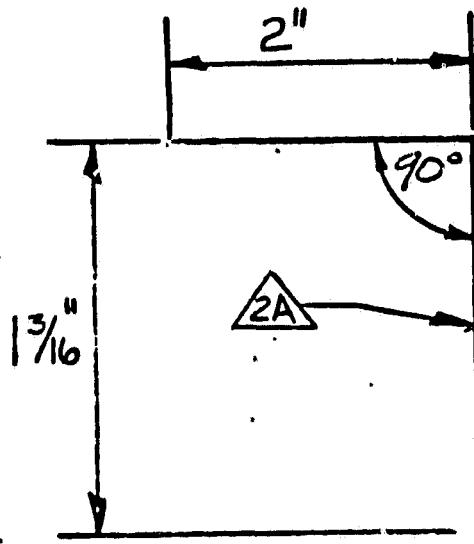
ARCO Solar, Inc.

Subsidiary of Atlantic Richfield Company
20554 Plummer Street Chatsworth, California 91311 (713) 998-0651

STARTER

SIZE	FSHM NO.	DRAWING NO.
A	270	012444 A
SCALE	NONE	SHEET 1 OF 1

APPLICATION			REVISIONS		
NEXT ASSY	USED ON	LTN	DESCRIPTION	DATE	APPROVED
012441	JPL		REL.FOR PROD. PER EO 192	1-8-81	DW
		A	REVISED PER EO 213	1-30-81	Ed/B



ORIGINAL PAGE IS
OF POOR QUALITY

~~CONFIDENTIAL DOCUMENT~~

For latest revision, check with
document control

3. LENGTH: 12' 0"

~~A~~ FINISH: A. .0015 THICK TEDLAR FILM, COLOR CHARCOAL #150BL30CC ON SIDE SHOWN.
B. OPPOSITE SIDE TO HAVE A CLEAR EPOXY WASH .0004, THICK MAX.

1. MATERIAL: 24 GAGE STEEL SHEET PER ASTM-A-446-76
GRADE "A" G-90 ZINC GALVANIZED.

NOTES:

UNLESS OTHERWISE SPECIFIED	CONTRACT NO.
DIMENSIONS ARE IN INCHES	
TOLERANCES ARE	
FRACTIONS DECIMALS ANGLES	
1/8" 1/16" 1/32" 1/64" 1/128"	
BREAK ALL SHARP EDGES	
01G 03D	
REMOVE ALL BURRS	
DIMENSIONS PER USASI Y 14.5	
FINISH	
APPROVED	
NO NOT SCALE DRAWING	

ARCO Solar, Inc.

Subsidiary of Atlantic Richfield Company
20554 Plummer Street Chatsworth California 91311 (213) 998-0667

'Z' CLOSURE

SIZE	FSCH NO.	DRAWING NO.
A	270	012443
SCALE	WEIGHT	

1 OF 1